COMPARISON OF MUSCLE ACTIVATION PATTERNS IN BOYS AND GIRLS DURING A SIMPLE LANDING TASK

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

2003

ACKNOWLEDGMENTS

The completion of this degree would not have been possible without the guidance and support of many people. First, I would like to thank my husband Jerry for the patience and love he has provided over the last 5 years and for putting his own career goals on hold while I pursued mine. This truly has been a joint endeavor for my family and will be an achievement shared by all. I would also like to express my gratitude to my parents who have always encouraged us to pursue our dreams and have provided constant support and encouragement over the years. I am grateful to my brothers and sisters for their words of support and for allowing me to turn their Florida vacations into a babysitting service. It certainly made everything more manageable.

I would like to express my thanks to my committee members who have challenged me to become a better clinician, researcher and educator. Dr. Tom Kaminski was responsible for the pursuit of this degree. I am grateful for his guidance, support and friendship over the last 5 years and for teaching me the ways of higher education. Dr. Meister has provided the clinical expertise in this area and is someone I greatly respect for his extraordinary wealth of knowledge. I am thankful to Dr. Mark Tillman who provided technical expertise in this biomechanics related project. I am grateful for his time and insight and for always providing a question to be answered for the next project. I would like to thank my newest member of the committee, Dr. Terese Chmielewski who agreed to sign on to this project at the end. Finally, I would like to express my thanks to students at San Jose Catholic School, Assumption Catholic School, and to Noraxon USA, Inc. for providing me with the equipment and technical support for this project.

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Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

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May 2003

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The passing of Title IX of the Educational Amendments of 1972 has resulted in increased participation of females in sports. Paralleling this has been a rise in the number of knee injuries seen in female athletes at all levels of competition. Specifically, these injuries involve the anterior cruciate ligament. Researchers have suggested that these injuries may be a result of differences in landing technique between males and females. Therefore, the purpose of this study was to compare quadriceps and hamstring muscle activity when landing from a jump in two groups of boys and girls. In addition, this study compared the knee flexion angle of boys and girls at initial contact in both groups.

A total of 40 children volunteered for this study. Ten boys and 10 girls between 5 and 6 years old (Group 1) and 10 boys and 10 girls between 10 and 11 years old (Group 2) performed a simple landing task. Results showed no difference in muscle activity and knee flexion angle between boys and girls in Group 1. Interestingly, there was a

significant difference in knee flexion angle between the boys and girls in Group 2 (P<.05). Girls landed with the knee in a more extended position (18°) while the boys landed with the knee in a more flexed position (31°). There was, however, no difference in muscle activity between the boys and girls in Group 2.

These findings suggest that girls are developing landing strategies that may put the knee in a more vulnerable position at a very young age. As the knee is positioned closer to extension, the quadriceps are in an optimal position to stress the ACL, and this becomes a potentially injurious position for the knee. The hamstrings, which counteract the anterior tibial translation, are not at the optimal position to provide the necessary stabilization and protection to the knee. As a result, it may be important to implement a training program that emphasizes proper landing strategies, particularly those strategies that work to increase knee flexion angle before the age of eleven.

CHAPTER 1
INTRODUCTION

Women's participation in sports has been on the rise since the passing of Title IX of the Educational Amendments of 1972. This law mandated that federally funded institutions provide equal opportunities for women in all educational programs, including intramurals, club sports, and varsity athletics. The passing of Title IX, as well as the heightened awareness of women's health and fitness has resulted in a dramatic increase in participation of women and girls in athletics.[1]

Before implementation of this law, participation of women and girls in sports was minimal. In 1972, only 1 of 27 high school girls played a varsity sport.[1] In 1998, that figure was 1 in 3. Growth in female athletic participation is seen throughout various levels of competition. In 1972, women comprised 14.8, 16.0 and 17.8% of all athletes at the Olympic, collegiate, and high school levels, respectively. In 1996, the numbers increased and women comprised 34.2, 39.1, and 40% of all athletes at the Olympic, collegiate, and high school levels, respectively.[1]

Paralleling this growth in female athletic participation has been an increased focus on the health of and injuries sustained by female athletes. Many authors have addressed issues unique to the female athlete, ranging from hormonal influence to discrepancy in injury patterns and rates.[2-15] The epidemic of anterior cruciate ligament (ACL) tears sustained by these athletes in sports such as volleyball, basketball, and soccer has yet to be explained. Recent attention has focused on epidemiological studies that suggest females have a 2-4 times increased risk of sustaining a noncontact ACL injury compared to their male counterpart in sports such as volleyball, basketball and soccer.[2-4,15-18] Arendt and Dick's[2] results of a 5-year evaluation of injury incidence for males and females in NCAA soccer and basketball programs are in agreement with most of the current literature. In basketball, the ACL injury rate for women was more than four times that for men. In soccer, females were two times as likely as men to have an ACL injury as a result of player contact and three times more likely to obtain an injury through a noncontact mechanism. While these sports are played with similar rules and on similar playing surfaces as their counterparts, the discrepancy in injury rate has yet to be explained.

Most injuries sustained by the female athlete occur through a noncontact mechanism with the knee position near extension.[19,20] Often athletes are landing, cutting or decelerating at the time of injury. Boden et al.[19] interviewed 89 athletes (100 injuries) who were able to recall the mechanism of injury for their ACL tear. Data were collected that included contact versus noncontact mechanism, position of knee and lower leg, direction of knee collapse, and direction of body twisting. Seventy-two percent of the athletes described a noncontact mechanism with basketball, football and soccer as the most common activity at time of injury. The average angle of knee flexion was 21° at time of injury, as the foot made initial contact with the ground. Boden and colleagues[19] suggest that abnormal motor patterns can cause the quadriceps to activate prior to the hamstrings, making it more likely for female athletes to sustain an ACL injury. Differences in muscle activation and landing mechanics have been demonstrated in males and females.[21-24] There are no studies that have compared muscle patterns in boys and girls during a landing task. Therefore, it seems necessary to evaluate the strategies incorporated by children during landing and examine any potential differences that may emerge during childhood.

Statement of the Problem

Female athletes are more susceptible than males to knee injuries. This discrepancy is demonstrated by the increased incidence of ACL injuries sustained in women. Researchers have proposed a variety of factors to explain this difference that can be divided into intrinsic and extrinsic factors. Intrinsic factors are not modifiable and include notch width, lower extremity alignment, hormonal influence, and laxity. Extrinsic factors are modifiable and consist of skill level, strength and activation patterns, and landing mechanics. It seems logical that the emphasis be placed on modifying the extrinsic factors in an attempt to prevent these injuries from occurring.

Forceful eccentric quadriceps muscle action has been implicated in ACL injuries. The strength of the hamstrings must be adequate to counteract the anterior tibial translation resulting from the quadriceps contraction. The eccentric quadriceps muscle action is seen during certain athletic maneuvers that require deceleration, landing or cutting. It is at this point in females that the knee is near extension and the simultaneous contraction of the quadriceps at low flexion angles can theoretically generate enough force to rupture the ACL. Differences in muscle activation and knee flexion angles at initial ground contact during an athletic maneuver have been detected in male and female athletes. As a result, training programs are implemented that attempt to reduce the risk of injury to the knee and incorporate safer landing and cutting strategies. Thus far, these programs have been shown to be effective in decreasing the incidence of injury in high school athletes.[25]

Much research has focused on the muscle activation patterns and knee flexion angles in collegiate athletes. It seems more logical to examine these factors in a group of younger athletes in order to detect when these patterns emerge. If an age range is detected, then training programs could be implemented before that age in hope of preventing further knee injuries. Therefore, the purpose of this study is to compare muscle activation patterns and knee flexion angles between boys and girls in two different age groups.

Research Hypotheses

This study has three main hypotheses. (Group 1 refers to children between 5 and 6 years old and Group 2 refers to the children between 10 and 11 years old.)

- **H1:** Boys and girls in Group 2 will demonstrate different muscle activation patterns in response to landing.
- **H2:** Girls in Group 2 will demonstrate smaller knee flexion angles compared to boys in the same age group.
- **H3:** Boys and girls in Group 1 will demonstrate similar muscle activation patterns and knee flexion angles in response to landing.

Definition of Terms

- Dynamic knee stability: the ability of the knee joint to remain stable when subjected to rapidly changing loads it often withstands during activity.[26]
- Neuromuscular control: unconscious activation of dynamic restraints occurring in preparation for and in response to joint motion and loading for the purpose of maintaining and restoring functional joint stability.[27]
- EMG normalization: procedure used to convert EMG data relative to a percentage of mean muscle activity collected 250 ms after initial ground contact during landing. This method of normalization was reported by Swanik et al.[28]

- Knee flexion angle: defined as the position of the knee at initial ground contact.
- Area value: area under the EMG curve, as calculated by multiplying each data value on the channel by the sampling interval and adding all the resulting values together.
- Mean value: simple average calculation of all the data values within the defined markers.
- Muscle preactivity: the amount of muscle activity after normalization that occurs 250 milliseconds before initial ground contact.
- Initial muscle activity at ground contact: the EMG values recorded at the onset of the footswitch which signals contact with the ground.

Assumptions

The following items were assumed to be true by the researcher:

- All subjects participated on a volunteer basis.
- All instruments were accurately calibrated.
- EMG electrode placement was optimal for obtaining measures of muscle activity.
- A modified Berg Balance Scale motor proficiency test would identify those children who can successfully perform the landing task.

Limitations

The following were potential limitations in this study:

- Testing outside a laboratory environment does not allow for collection of ground reaction forces.
- Findings can only be applied to the specific age groups tested and may not be indicative of landing patterns in children of different ages.
- Because of the age of the subjects, a simple landing task must be assessed.
- Subjects were required to jump from a set box height of 25.4 cm.

Significance

The increased incidence of ACL injuries in females concerns both clinicians and researchers. A definitive contributing factor has yet to be established, although the focus appears to be on developing prevention and intervention strategies to reduce the potential risk for injury. Differences in muscle activation during athletic activities have been demonstrated between college and high school male and female athletes. As a result, athletes can be required to participate in conditioning programs that may alter landing mechanics and increase muscle strength. It seems logical that we need to determine when these patterns, specific to females, emerge.

CHAPTER 2
REVIEW OF LITERATURE

Introduction

Proprioception was first described by CS Sherrington in 1906.[29] He stated ". . . a character of the stimulations occurring in this deep field is that the stimuli are traceable to actions of the organism itself, and are so in much greater measure than are the stimulations of the surface field of the organism. . . . the deep receptors are termed proprio-ceptors and the deep field a field of proprioception."[29] Through the century proprioception has been discussed frequently in scientific literature. Its definition has varied and the concept is not always clearly or correctly interpreted. As a result of the misuse of terminology relating to the somatosensory system, researchers have collaborated to redefine proprioception.[30]

Sherrington's definition of proprioception pertains to all neural inputs originating from the muscles, tendons, joints and deep tissue proprioceptors. These signals are transmitted to the CNS for processing, which ultimately regulates reflexes and motor control. Three submodalities of proprioception have more recently been defined to include joint position sense, kinesthesia, and sensation to resistance.[31] Joint position sense is associated with the sense of joint position[30] and is the ability to consciously recognize where one's joint is oriented in space.[31] Kinesthesia is associated with the sensation of joint movement, either from internal or external forces[30] and describes one's ability to consciously appreciate joint motion.[31] Sensation of resistance is one's ability to appreciate force generated with a joint.[31]

Joint position sense and kinesthesia are more often assessed as measures of proprioception, although all three submodalities contribute to maintenance of neuromuscular control. Kinesthesia is assessed by measuring threshold to detection of passive motion (TTDPM). TTDPM, commonly tested at a slow velocity (.5-2.0°/sec), is thought to stimulate Ruffini or Golgi type mechanoreceptors.[5] Because this test is performed passively, the joint receptors are maximally stimulated while the muscle receptors are minimally stimulated.[32] Joint position sense is assessed by measuring one's ability to reproduce a target position, actively or passively.

A more progressive and inclusive word to describe the relationship between sensory and motor pathways is termed sensorimotor.[30] Sensorimotor system is the system of sensory, motor, and central integration and processing components involved with maintaining joint homeostasis during functional activity.[30] Proprioceptors are the afferent component of the sensorimotor system and provide awareness of joint position and joint motion at both the voluntary and reflex initiated levels.[33]

Dynamic joint stability and neuromuscular control must also be defined to understand the importance of proprioceptive feedback in controlling movement and joint stability. Dynamic joint stability is the ability to appropriately activate muscles to stabilize a joint,[33] and neuromuscular control is the unconscious activation of dynamic restraints occurring in preparation for and in response to joint motion and loading for the purpose of maintaining and restoring functional joint stability.[27] Both rely on a complex system integrating the sensory and motor pathways. Dynamic joint stability and neuromuscular control are influenced by proprioceptive, kinesthetic, visual and vestibular information.[34] Proprioception is a key component of joint stability and neuromuscular control because afferent input directly influences the efferent response that allows the neuromuscular system to maintain a balance between stability and mobility.[7]

Differences in muscle activation patterns and strength in the hamstring and quadriceps muscles have been detected between males and females and may contribute to the increase in knee injuries among female athletes.[2,24] The ability for females to achieve adequate joint stability during athletic activities continues to be researched. A review of proprioception and its contribution to knee joint stability follows. Also, the role of the quadriceps and hamstring muscles with implications for anterior cruciate ligament (ACL) injury will be discussed. [3,4,15,17]

Mechanoreceptors

Mechanoreceptors initiate the afferent pathway of proprioceptive feedback to the brain and provide input to the CNS regarding tissue deformation.[35] There are many types of mechanoreceptors- cutaneous, muscle, joint capsule and ligament receptors- with each responding to a different stimuli and giving specific afferent information that modifies neuromuscular function.[7,33,35] Articular mechanoreceptors include the Ruffini endings and Pacinian corpuscles. Muscular mechanoreceptors include muscle spindles and Golgi tendon organs (GTOs).

Skin Mechanoreceptors

Cutaneous mechanoreceptors are initiated as a result of joint rotation, which causes the skin to be stretched. These neurons could essentially signal joint position or motion.[35,36] Researchers have investigated the contribution of skin mechanoreceptors to proprioception by two methods. The first is to electrically stimulate individual afferents and note the resulting sensations.[35] The second method requires blocking the cutaneous sensory mechanism, or blocking the sensory mechanism in other structures, and recording changes in sensation as the joint is moved.[35]

The extent to which these mechanoreceptors play an important role is questionable. Some studies examining the effects of taping and bracing on proprioception support the role of cutaneous receptors contributing to proprioception.[37,38] The stimulation of the cutaneous afferents through the application of athletic tape has enhanced proprioception and joint position sense in the ankle.[37,38] Cutaneous afferents of the hands and fingers have been shown to be essential in joint position sense,[39] although their effect on kinesthesia is still debatable.[40] Contrary to these findings, studies eliminating the cutaneous afferents through anesthesia of the skin adjacent to the joint had no effect on proprioception and joint position sense.[35,41] If cutaneous afferents play a role in proprioception, then it is a minor one.[35]

Joint Mechanoreceptors

Ruffini endings and Pacinian corpuscles are articular mechanoreceptors that are present in the capsule, cruciate, and collateral ligaments in the knee. The Ruffini endings are slow adapting and exhibit a low threshold to mechanical stress.[42,43] They may signal joint position, intra-articular pressure, amplitutude and velocity of joint rotations.[42,43] These receptors, along with free nerve endings, are considered the primary receptors in the anterior cruciate ligament.[44]

Pacinian corpuscles are rapidly adapting and demonstrate a low threshold to mechanical stress.[42,43] They are silent during static conditions and also when the joint is rotated at a constant speed. They are very sensitive to acceleration and deceleration,[42] and fire near the extremes of movement, discharging during both extremes of knee flexion and extension.[45]

Overall, the evidence is inconclusive that articular receptors in any joint are critical for the conscious awareness of joint position.[46] It appears that information about the speed and direction of movement is impaired minimally by the loss of articular receptor activity. They do appear to contribute to deep pressure sensation that occurs near the end range of motion.[46] If articular receptors and cutaneous receptors are not primary contributors to proprioception, then muscle mechanoreceptors play a more crucial role.

Muscle Mechanoreceptors

Information regarding changes in muscle length and force are provided from three types of mechanoreceptors located in the muscle. Two types are stretch receptors, known as primary and secondary spindle receptors. The third type of receptor is the Golgi tendon organs (GTOs).[45]

Muscle spindles, located within the belly of skeletal muscles contain specialized fibers, called intrafusal fibers, which are surrounded by connective tissue. The nuclear bag and nuclear chain fibers are types of intrafusal fibers. These intrafusal fibers are innervated by efferent fibers, the gamma motor neurons.[47] Extrafusal fibers are the regular muscle fibers that are innervated by the alpha motor neurons.[47]

The central portion of the intrafusal fibers (noncontractile) is surrounded by sensory neurons called primary and secondary endings.[48] These endings are stimulated as a result of stretching the central region of the intrafusal fibers and the degree to which they are stretched results in a directly proportional increase in impulses. The primary endings respond to a change in length of the spindle. This also results in an increase in impulses, only while the length is actually increasing. The secondary endings fire as long as a stretch is maintained. This is considered the static response of the muscle spindle.[48]

The muscle spindle sends signals into the nervous system by afferent fibers, group Ia and group II afferents, and is controlled by the efferent fibers of the CNS.[47] Muscle spindles provide information regarding absolute length and the rate of change of the length (velocity) of the muscle via spindle Ia afferents. When signals are sent to the muscles through the alpha motor neurons, the gamma system is also stimulated, so that intrafusal fibers contract and shorten the spindles at the same time as the muscle shortens. This prevents the muscle spindles from opposing a muscle contraction.[48]

Spindle functioning is essential for awareness of limb position (proprioception) because the degree to which a muscle is stretched indicates angular joint changes. In addition to detecting movement, spindles contribute to the presetting and regulation of muscle stiffness.[49] Muscle spindles provide feedback to the nervous system about muscle length changes and most likely help correct movement and ensure that the movement is appropriate for the desired task.[49]

Golgi tendon organs are located within the tendons of muscles and are activated when muscle contraction pulls on the tendon. Sensory information that is detected by the GTOs is transmitted via Group Ib sensory afferents.[32] The receptor endings of the afferent neurons are distorted and an increase in activity of the GTOs is seen. This increased activity causes inhibition of the motor neurons that innervate the muscles that were stretched and excite the motor nerves of the antagonistic muscle.[32] Golgi tendon organs respond to changes in muscle and tendon tension and function as a protective mechanism.[32] They are more sensitive to contraction-induced changes in muscle tension and are less sensitive to changes in stretch-induced tension.[49]

Researchers readily agree that muscle afferents contribute to kinesthesia and actually play an important role, based on three lines of evidence. Muscle pulling, muscle vibration, and the elimination of joint and cutaneous signals are the procedures that have strongly supported the role of muscle receptors in proprioception.[40] Knee proprioception may be predominantly determined by muscle receptors in mid range of motion, with joint receptors playing a secondary role.[43] At extreme ranges of motion, the muscle and joint receptors are equally important contributors to knee joint proprioception.

Afferent Feedback and Reflexes

Dynamic joint stability is defined as the ability to appropriately activate muscles to provide stability to a joint.[33] Proprioception plays a critical role in achieving dynamic joint stability, the end point of proprioception.[33] If voluntary movement initiated at the cerebral cortex is too slow to prevent injury, the emphasis is placed on the spinal afferent-efferent arcs. The initiation of these arcs may be more important in providing joint stability and preventing injury while participating in "at risk" maneuvers.[33] A timely response of the afferent input, regardless of its point of origin, is necessary in providing joint stabilization.

A neural reflex, such as a monosynaptic reflex, is an involuntary reaction in response to a stimulus applied to the periphery and transmitted to the nervous centers in the brain and spinal cord.[43] The receptors in the ligaments and muscles surrounding the knee are involved in reflexes that provide stability and stiffness to the joint. A ligamento-muscular reflex has been demonstrated in the anterior cruciate ligament.[50] As the anterior cruciate ligament is subjected to large forces, specifically when the tibia is displaced anteriorly with respect to the femur, the hamstring muscles contract. Contraction of the hamstring muscles reduces the anterior displacement of the tibia and decrease stress on the ACL. This ligamentomuscular protective reflex is very important because it is elicited only during extreme load on a ligament, when injury and damage is likely.[43] Hogervorst et al.[44] however, do not support the idea of a ligamentomuscular reflex. They argue that researchers are unable to differentiate between afferent-nerve signals emanating from the anterior cruciate ligament, capsule and muscles. Thus, evidence of the presence of this protective reflex is inconclusive.

Another reflex also functions to provide a protective mechanism to the knee, if the ligamentomuscular reflex fails. Low-level loads from the joint capsule and muscle spindle receptors will also trigger a muscle contraction.[51] For example, quadriceps contraction results in anterior displacement of the tibia on the femur. Hamstring muscles are elongated and muscle spindles within the hamstrings fire and cause the hamstrings to contract. This monosynaptic stretch reflex, resulting in a hamstring contraction, reduces anterior displacement of the tibia. Golgi tendon organs are also activated in response to a muscle contraction. The polysynaptic reflex causes cessation of the muscle contraction in which they are housed. This protective mechanism prevents tendon rupture that may result from an excessive muscle contraction.[43]

There is some controversy over the mechanism by which the CNS processes the afferent information and regulates neuromuscular control. When a joint sustains an imposed force, a reactive reflex response is characteristic of the feedback mechanism. A feedforward mechanism is characterized by preactivated muscle control in anticipation of loads.[16] The preactivation theory suggests that prior sensory feedback (experience) concerning the task is used to preprogram muscle activation patterns. This preactivation can provide quick compensation for external loads and enhance dynamic joint stability.

Feedforward motor control uses previous information and builds a model depicting the expected conditions. These centrally generated motor commands are responsible for preparatory muscle activity and execute very quick motor commands after being initiated.[34] Sensory information is used to evaluate the results and help program future muscle patterns. Unexpected events occurring during these movements may be identified by muscle and joint receptors and may be used for future planning, not for reflex stabilization.[52]

Many reflex pathways responsible for adjusting ongoing muscle activity characterize the feedback mechanism. Information from joint and muscle receptors is used to coordinate muscle activity and allow for completion of the task.[52] It results in long conduction delays and is therefore best used to maintain posture and regulate slow movements.[34]

Both mechanisms of motor control can enhance dynamic joint stability. Each time the sensory and motor pathways are stimulated, the synapses that receive the signals become more capable of transmitting the signal next time. The frequent facilitation enhances memory about tasks for preprogrammed motor control and reflex pathways for reactive neuromuscular control.[52]

Female ACL Injuries

The role of the mechanoreceptors and proprioceptive deficits may offer one explanation for the cause of ACL injuries among male and female athletes.

Proprioception, as mentioned previously, plays a critical role in achieving neuromuscular control and maintaining dynamic joint stability. Deficits in proprioception may result in altered neuromuscular control during athletic maneuvers. This area has received much attention, as female athletes are participating and competing in sports at higher levels and in greater numbers.

Women's participation in sports has been on the rise since the passing of Title IX of the Educational Amendments of 1972. This law mandated that federally funded institutions provide equal opportunities for women in all educational programs, including intramural, club sports, and varsity athletics. The passing of Title IX, as well as the heightened awareness of women's health and fitness has resulted in a dramatic increase in participation of women and girls in athletics.[1]

Paralleling this growth in female athletic participation has been the increased focus on the health and injuries of female athletes. Many authors have addressed issues unique to the female athlete, ranging from the hormonal influence on neuromuscular control to the discrepancy in injury patterns and rates.[2-6,8-10,12,14,15,53-56] The epidemic of ACL tears sustained by female athletes in certain sports has yet to be explained. Researchers conducting epidemiological studies suggest that females have a 2-4 times increased risk of sustaining a noncontact ACL injury compared to their male counterpart in sports such as volleyball, basketball and soccer.[2,3,15,56]Arendt and Dick's[2] results of a 5-year evaluation of injury incidence for males and females in NCAA soccer and basketball programs are in agreement with current literature. In basketball, the ACL injury rate for women was more than four times that of the men's game. In soccer, females were two times as likely to have an ACL injury as a result of player contact and three times more likely to obtain an injury through a noncontact mechanism. While males and females play with similar rules and on similar playing surfaces, the discrepancy in injury rate is perplexing.

The majority of injuries sustained by the female athlete occur through a noncontact mechanism. This is critical when researchers are trying to understand and explain why some women seem more prone to injury. The mechanisms of this noncontact injury give insight to possible contributing factors Ferretti et al.[56] collected injury information on 52 cases involving male and female volleyball players. They reported that injury occurred during a phase of jumping in 48 cases. Injuries were reported during take-off in 7 cases. In addition, 43 patients described the injury mechanism with 22 reporting an external valgus rotation stress, and 21 reporting an internal valgus rotation stress. Boden et al.[19] interviewed 89 athletes (100 injuries) who were able to recall the mechanism of injury for their ACL tear. Seventy-two percent of the athletes described a noncontact mechanism with basketball, football and soccer as the most common activities at time of injury.

The ACL epidemic in female athletes has yet to be understood. Due to the nature of the noncontact mechanism of injury, many researchers propose a variety of factors that may increase the incidence of injury.[2,3,6,9,54,57] Possible explanations include differences in muscle strength, lower extremity alignment, notch width, hormonal influence on ligament laxity, conditioning, and skill level. These potential contributors to injury are often classified as intrinsic or extrinsic factors. Intrinsic factors are inherent to the athlete and are not controllable. They include joint laxity, lower extremity alignment, intercondylar notch dimensions, and hormonal influence. Extrinsic factors are related to the sport or environment and include body movement, muscular strength, shoe-surface interface, and skill level.[3,6,8,58]

As mentioned previously, intrinsic factors are innate to the athlete and are not modifiable. Therefore, prevention must center on the extrinsic or controllable factors that may be modified through training and conditioning. Although the cause of the ACL injury is most likely multi-factorial, specific training and conditioning programs appear to decrease the incidence of injury.[25,59]

Laxity

The relationship between ligament laxity and injury has not been determined. In addition, there are conflicting results when discussing the association of gender with laxity. In 1970, Nicholas[60] studied the relationship between "loose" joints and incidence of injury in professional football players. He assessed the upper and lower extremities of the players through 5 arbitrary performance tests. Each was classified as "loose" or "tight." Of the 39 players who were classified as "loose," 28 (72%) ruptured their knee ligaments. Contrary to the findings of Nicholas, Grana and Moretz[61] concluded that no correlation could be found between ligamentous laxity and the occurrence or type of injury. Male and female subjects were included in the study and they reported that female athletes demonstrated looser joints than their male counterparts, but they had tighter joints than those not participating in sports.[61]

Huston and Wojtys[23] noted that female athletes and controls demonstrated more anterior tibial laxity than their male counterparts. Also, the male athletes demonstrated significantly less anterior tibial translation when compared to the female athlete, and male and female control groups. Rozzi et al.[24] also assessed anterior tibial laxity with a

KT-1000 in male and female collegiate athletes (basketball and soccer). Again, the results demonstrated an increase in anterior tibial translation in women compared to men. Anderson et al[62] reported no difference in laxity between men and women, making it difficult to draw a definitive conclusion on this "contributing" factor.

One may argue that the testing of knee joint laxity in a static position is not indicative of the physiological changes that take place within the ligament during exercise. Many studies have examined the effects of exercise on ligament laxity and conclude that there is an increase in ligament laxity following exercise.[63,64] Therefore a clear understanding of how the ligament responds to load can be seen in the studies examining the properties of the ligament during and following exercise.

Comparing results of these laxity studies is difficult because of the difference in commercial instrumentation used. Moreover, the findings must be interpreted with caution given that an increase in laxity compared to the bilateral limb, or an increase in the hypermobility of one's joints has not been definitively correlated to an increased incidence of injury.

Although the relationship between laxity and injury has yet to be clearly established, researchers have reported a decrease in proprioception with an increase in anterior tibial translation.[24,55] The proprioceptive information originates at the level of the mechanoreceptors located within the capsule, ligament, muscle or tendon. Laxity causes a disruption of the mechanoreceptors, as is evident by the deficits in proprioception in ACL-deficient subjects.[65,66] Good et al.[67] demonstrated no difference in joint position sense after acute disruption of the ACL. They stated that proprioceptive deficits are typically reported with chronic ACL deficient subjects and the subjects chosen (acute ACL disruption) in their study may explain the discrepancy in results.

In addition to reporting laxity, Rozzi et al.[24] measured knee proprioception and strength. They reported a decrease in the ability of females to detect passive motion when moving into knee extension. They discussed the relationship between laxity and deficits in proprioception, although they were not able to conclude that the increased laxity caused a decrease in joint position sense. Their findings of an increase in ligament laxity and a decrease in detection of passive movement into extension may provide additional insight into the increased number of ACL injuries. As mentioned previously, most injuries are noncontact and are sustained while the athlete's knee is positioned near terminal extension. If the deficit in proprioception occurs toward extension, then females may have difficulty detecting this potentially injurious position and as a result not have adequate joint stability.

Loudon[55] examined the relationship between genu recurvatum and joint position sense in women. Loudon's measure of proprioception included a voluntary repositioning of an active movement. This method of proprioception measurement is not as common as threshold to detection of passive movement (kinesthesia) or voluntary repositioning of a passive movement. However, the procedure is more practical and functional because the receptors that are stimulated through the initial voluntary positioning of the target angle will be activated while performing the repositioning test. Joint position sense was also measured in a closed kinetic chain position on a leg press machine. This places the patient in a more functional position and allows for an accurate assessment of joint repositioning.

The type of proprioceptive measurement (voluntary vs. passive) may stimulate different receptors. Passive repositioning stimulates the joint receptors to a greater extent than the muscle receptors; active repositioning is thought to primarily stimulate the muscle receptors although the joint receptors do contribute as well.[5] Isolating the contribution of a single type of receptor is difficult, and it is more commonly thought that the joint, ligament, and muscle receptors contribute in a synergistic way.

Muscle Activation Patterns

Extrinsic factors, unlike the intrinsic factors, are modifiable and have been the focus of researchers studying ACL injuries in female athletes. Researchers have investigated muscle firing patterns in males and females,[23,24] flexibility and injury rate,[68] and strength characteristics in healthy and injured populations.[24,68-74]

The relationship between strength deficits and knee injury has not been established. A gross muscle imbalance and a decrease in flexibility have been suggested to increase the probability of injury.[69] On the other hand, Grace et al.[68] assessed strength in a group of 172 secondary school football players on an isokinetic dynamometer prior to the start of season. They reported no relationship between thigh muscle imbalance and knee injury. Although neither study specifically addressed the hamstring-quadriceps muscle imbalance in relation to ACL injuries, clinical experiences suggests that a deficit in the hamstring-quadriceps (H:Q) ratio could be a contributing factor to ACL injury.

Differences in muscle firing patterns between males and females have been detected in response to an anterior tibial translation (ATT) perturbation[23] and in the performance of a landing task.[24] Huston and Wojtys[54] reported that female athletes appeared to rely more on their quadriceps muscles in response to the ATT, while the males and female controls relied more on their hamstrings. This was apparent when evaluating the muscle recruitment order preference at the intermediate phase of the response segment. The difference in muscle response may be a result of the training programs that female athletes participate in and therefore modification may be necessary to alter the recruitment strategies. Rozzi et al.[24] noted an increase in lateral hamstring activation subsequent to landing in females compared to males. The authors felt that this may have been a compensatory mechanism because females have an increase in ligamentous laxity and this increase in hamstring activity may assist in joint stability. The finding of increased lateral hamstring activity in females needs to be further investigated to conclude that it is a result of an unstable or lax knee.

Studies have examined the time to generate peak torque and the angle of peak torque between males and females in isokinetic testing.[23,24,74] Huston and Wojtys[23]studied neuromuscular performance in elite female athletes. Isokinetic testing at 60°/sec indicated that the time to generate hamstring peak torque for female athletes was 102msec slower than the male athletes and minimally slower compared to female controls. The female athletes generated maximum hamstring torque after generating maximum quadriceps torque. Testing at 240°/sec revealed that females athletes were significantly slower than male athletes in generating hamstring peak torque. Contrary to Huston and Wojtys,[54] Rozzi et al.[24] reported no difference between male and female athletes in their ability to generate peak torque in the knee flexors and extensors at 180°/sec. It does appear these studies examined the time to peak torque in a concentric:concentric mode for knee flexors and extensors.

The force generated through an eccentric quadriceps contraction commonly seen during a deceleration, landing or cutting movement, may contribute to ACL injury.[19,21,75] Colby et al.[21] and Malinzak et al[22] studied quadriceps and hamstring muscle activation and determined knee flexion angle at initial ground contact during running, cutting, stopping and landing activities. Colby et al.[69] reported an increase in quadriceps activation prior to foot strike with the greatest activity occurring in mid range of the eccentric motion.[21] Hamstring muscle activity also increased before foot strike and decreased at or after foot strike for all maneuvers except landing. Malinzak et al[70] studied knee joint motion patterns between men and women during running, side-cutting and cross-cutting. It appeared that women had lower knee flexion angles, more knee valgus angles, greater quadriceps activation and lower hamstring activation compared to men in the stance phase of the three athletic maneuvers. If the maximal eccentric quadriceps contraction occurs while the hamstrings are minimally activated and the knee is toward extension, then a significant anterior displacement of the tibia may result. Boden et al.[20] proposed that abnormal motor patterns that result from landing off balance could cause the quadriceps to activate prior to the hamstrings, causing an athlete to sustain an ACL injury.

The average angle of knee flexion has been reported to be near extension[20] and at 21 ° at time of injury[10]. Nissel[76] reported that the patellar tendon-tibia angle was slightly higher in women at knee flexion angles less than 60°. The higher patellar tendon-tibia angle results in greater tibiofemoral shear stresses during knee extension. As this angle increases with extension, women who play with a more upright posture may be prone to ACL injury.[19]

Colby et al.[21] discussed the level of activation of the eccentric quadriceps contraction exceeding that of a maximal voluntary contraction during ballistic type movements such as those involved in an athletic setting. "The stretching of the muscle by external forces increases internal muscle force by a mechanical mechanism."[21] This allows use of elastic energy and an increase in nervous system activation. The increase in stored energy and activation of the nervous system augment the quadriceps forces at foot strike, therefore increasing the likelihood of injury to the ACL. A theoretical model examining the forces generated during an eccentric contraction exceeded 2000N,[10] the force reported to rupture the ACL.[77]

Hamstring:Quadriceps Strength Ratios

There is a plethora of research examining the strength relationship between the quadriceps and hamstrings and the H:Q ratios. Huston and Wojtys[54] emphasize the importance of establishing a "balance of power" between the quadriceps and hamstrings in normal knee function because the quadriceps muscle can produce forces in excess of those needed for ligament failure. Typically, isokinetic testing allows the clinician and researcher to evaluate the relationship between these muscle groups in a variety of ways. Peak torque, average torque, time to peak, and ratios are some ways that strength measures are assessed. Consistent reporting of these values in the scientific literature has not taken place, since some values are reported as gravity corrected and/or some ratios are reported after being normalized for body weight. As a result, it is difficult to compare results with previous studies.

Traditionally, reciprocal muscle group ratios are reported for each mode of contraction. This implies that concentric (or eccentric) contraction would take place for the knee flexor and extensors simultaneously. True knee joint motion allows an eccentric (concentric) quadriceps contraction and a concentric (eccentric) hamstring contraction during flexion (extension). Although the traditional values are informative, a better indication of the relationship between the muscle groups (i.e. quadriceps and hamstrings) would be the ratio of the eccentric hamstring (H_{ecc}) peak torque to concentric quadriceps (Q_{con}) peak torque and the ratio of the concentric hamstring (H_{con}) to eccentric quadriceps (Q_{ecc}) peak torque. The anterior shear forces resulting from a quadriceps contraction are counteracted by the eccentric contraction of the hamstrings. Thus, the functional H_{ecc}:Q_{con} may represent the joint stabilizing effect of the hamstrings during knee extension. The H_{con}:Q_{ecc} values represent the stabilizing effects of the hamstrings during an eccentric quadriceps contraction. As mentioned previously, some researchers have implicated the knee extensor mechanism and a forceful eccentric quadriceps contraction as providing the necessary force for ligamentous damage.[19]

The more functional approach to reporting strength ratios in the knee has recently been conducted using agonist to antagonist muscle group ratios for the quadriceps and hamstring muscles.[72,78,79] Aagaard et al.[79] argue that providing strength information on the nature of the agonist and antagonist muscle group relationship will create a clear picture of the true dynamic nature of the muscles' function. The hamstrings function synergistically with the ACL,[50,80-82] resisting the forces of anterior tibial translation, whereas the quadriceps contraction acts as an antagonist at knee flexion angles less than 45°, significantly increasing the strain on the ACL.[83]

Typically, strength ratios of the thigh musculature when reported as concentric hamstrings to concentric quadriceps range from .55 to .85.[39,70,73,84] Hole et al.[72] examined the traditional and more functional dynamic control ratios in ACL deficient subjects. H_{ecc}:Q_{con} values were .70 for the injured and normal leg. H_{con}:Q_{ecc} values were .47 and .42 for the injured and normal leg, respectively. Aagaard et al[79] reported functional ratios varied between .3 and 1.0 for peak torque in nine track athletes, 4 females and 5 males.

Differences in strength have been reported between males and females in the hamstring and quadricep muscles, when normalized for body weight.[23,70,85] Researchers also have examined the time it takes to generate peak torque in the quadriceps and hamstrings, as well as the angle of peak torque during knee flexion and extension. Results are conflicting when comparing males to females in determining the time it takes to generate peak torque.[23,24]

The angle of peak torque provides information on the mechanical properties of the muscles and their ability to generate force at a specific point in the range of motion. Kannus and Beynnon[74] compared the peak torque angles during knee flexion and extension in males and females. They noted that the mean peak torque for hamstrings occurred significantly later in females (37° as compared to 33°for males) during testing at 60°/sec and occurred at 44° for females and 40° for males when testing at 180°/sec. Some suggest that structural or physiological differences between males and females may account for differences in strength.[83,84]

Westing and Seger[86]reported mean knee angles for concentric and eccentric quadricep and hamstring muscle strength tests in physically active females. At 60°/sec the hamstrings and quadriceps reached peak torque concentrically at 25° and 59° respectively, and eccentrically at 12° and 61°. When examining specific angles of peak torque in the hamstrings and quadriceps, we may understand the relationship between these muscles and their ability to providing dynamic joint stabilization.

The role of the muscles is important, although they alone may not prevent an injury from occurring because most injuries in sports occur very rapidly. Pope et al[87] simulated a MCL injury during skiing and found that ligament loading began 39 milliseconds after the event was initiated, ligament rupture occurred at 73 milliseconds and a forceful sustained contraction was not recorded until 215 milliseconds after the event was initiated. The authors suggested that the latencies demonstrate muscular responses are not adequate to prevent injury, although limitations should be noted with the study. The design did not allow from any muscle activity prior to initiation of load to the MCL. In a sport-specific situation, there will be muscle pre-activity and ongoing modulation of muscle stiffness, thus reducing the time to achieve a significant motor response. Because there are many factors associated with injury, emphasis must be placed on those that are modifiable in order to decrease the incidence.

Training

Training and rehabilitation programs often are implemented to prevent injury, especially in the knee. Protocols have been established for rehabilitating the knee joint after ACL injuries. Fitzgerald et al.[88] investigated one such protocol by comparing two groups of patients (a) standard traditional rehabilitation protocol or (b) standard traditional protocol enhanced with perturbation training. Traditional training consisted of open and closed chain exercises and agility drills; perturbation training incorporated progressively challenging exercises performed on rocker and roller boards. Treatment outcome was determined from scores on the Knee Outcome Survey's Activities of Daily

Living Scale and Sport Activity Scale, scores on a series of single-limb hop tests, measurements of maximum isometric quadriceps femoris muscle force output and the group frequency of unsuccessful rehabilitation. The findings indicated that the perturbation-training program reduced the risk of continued episodes of giving way and allowed the subjects to maintain their functional status for longer periods. The researchers felt this enhanced training allowed the subjects to acquire protective compensatory neuromuscular adaptations that would allow the neuromuscular system to adapt to forces about the knee in a controlled, yet progressive program. A program such as the one tested in this study may adequately prepare the body for unexpected perturbations and initiate a protective mechanism.

Clinicians have assessed the success of training and rehabilitation protocols for patients and athletes. Strength and conditioning coaches provide athletes with the appropriate training program that will enhance performance and prevent injury. With the increase in female athletic participation and the heightened awareness of ACL injuries sustained by these females, researchers have designed a training program that may offer the necessary protection to the knees of female athletes.[25,59] Hewett et al.[59] tested the plyometric jump-training program on landing mechanics and lower extremity strength in 11 female volleyball players. Nine male subjects were matched to the female subjects, with similar demographics. This program, designed to decrease landing forces and increase vertical height, lasted for 6 weeks with subjects training approximately 2 hours a day, 3 days a week (on alternating days). Results revealed a decrease in peak landing forces (22%) and a decrease in abduction and adduction moments (50%). Females demonstrated lower landing forces and lower abduction and adduction moments after training. These results suggest altered muscular control of the lower extremity with possible changes in abduction and adduction muscle strength. Flexion and extension moments after training did not change, although the male subjects demonstrated knee extension moments that were three times that of females. The knee extension moment, indicating net hamstring activity, may suggest that males use the hamstrings to counteract the high peak landing force. The training program also resulted in a 26% increase in isokinetic peak torque of the hamstrings in the nondominant leg and a 13% increase in the dominant leg. In addition, the hamstring-to-quadriceps muscle peak torque ratio increased significantly.

Hewett et al.[25] continued researching the effects of the plyometric training program on knee injury incidence. They conducted a prospective study involving 43 sports teams (basketball, soccer, and volleyball) from 12 local high schools. A total of 1,263 subjects were tracked through the study over the course of one year. Three groups consisting of trained females (N=366), untrained females (N=463) and untrained males (N=434) were monitored throughout the season. A total of 14 serious knee injuries were reported among the athletes monitored and a significant difference in injury rate was reported among the three groups. The untrained female group demonstrated a higher incidence of injury than the untrained male group, but there was no significant difference between the trained females and untrained male group. They argued that neuromuscular training might decrease the risk of injury in female athletes by increasing the dynamic stability of the knee joint.

In addition to the strength training program described by Hewett et al.,[59] another prevention strategy may include proprioception training.[89] Typically, these programs have been established and implemented after injury and surgery. As Rozzi et al.[24] and Loudon et al.[55] suggested, an increase in laxity might be related to a decrease in proprioception. As a result of the laxity, ligamentous receptors are not sensitive enough to detect changes and provide feedback to the muscle and joint receptors. This may be evident by the inability of females to detect passive movement near terminal extension, which is most often the described position at the time of injury.

Researchers have examined the effects of balance board training on the prevention of injuries to female athletes. Soderman et al.[90] examined the effects of a lower extremity training program consisting of 5 balance board training programs on the incidence of injury in 221 female soccer players. They reported no difference in injury incidence between the control and trained group. Wedderkopp et al.[91] studied the effects of ankle disk in female handball players and concluded that those who did not participate in the training were 5.9 times as likely to be injured as those who performed the training. It is still unclear if the balance training programs are effective in reducing the likelihood of injury.

The development of training programs appears to decrease the incidence of knee injury in female athletes by altering muscle activity and modifying the "at risk" maneuvers. Therefore, it seems logical to focus on addressing the extrinsic factors as a means of preventing serious knee injuries. It is important that these training programs are targeting the proper muscles. If the theory that an eccentric quadriceps contraction at low knee flexion angles can generate enough force to damage the ACL, then it would seem that programs emphasize strengthening of the hamstrings to counter the anterior tibial translation. First, we must examine the relationship between the quadriceps and the hamstrings in both concentric and eccentric modes at the smaller knee flexion angles where injury is most likely to occur. Clinicians then may focus on strengthening the quadriceps or hamstrings as deemed necessary with the ultimate goal of reducing the incidence of knee injury.

CHAPTER 3
METHODS

Subjects

Forty subjects [10 boys and 10 girls between the ages of 5 and 6 (Group 1) and 10 males and 10 females between the ages of 10 and 11 (Group 2)] with no prior history of knee injury were recruited from local elementary school athletic programs as participants in this study. These ages were chosen for several reasons. The age range of subjects in Group 1 was selected because it is around this time that children have the motor skills to perform a single leg landing task.[47] It is also during the early years that children are beginning to learn a landing strategy as they become more active and involved in extracurricular activities. The age range of subjects in Group 2 ages was selected to allow for testing of prepubescent females. That was important in order to eliminate any possible hormonal influence on neuromuscular activity.[92-94] Additionally, inclusion criteria required the subjects in Group 2 to have a minimum of 3 years playing experience in organized basketball. This allowed for testing subjects who were familiar with a landing task and who also were athletically inclined and involved in a sport requiring landing, cutting, and jumping. Testing was conducted on the skilled leg of each subject. Skill leg was defined as the preferred leg to kick a ball.

The Institutional Review Board (IRB-02) at the University of Florida approved the test protocol and appropriate consent documents. Parents were asked to read the brief description of the testing protocol prior to signing the consent form (Appendix A). A child assent script was read to all children prior to their participation in this study (Appendix B).

Instrumentation

The Noraxon Telemyo (Noraxon USA, Inc., Scottsdale, AZ) telemetry surface electromyographic (EMG) system was used for data collection. This 8 channel portable unit also allowed for integration and synchronization of the NorSwitch (Noraxon USA, Inc., Scottsdale, Arizona) footswitch system and the NorAngle (Noraxon USA, Inc., Scottsdale, Arizona) electrogoniometer system. Muscle signal activity was collected from beneath the surface electrodes and relayed to a battery-operated transmitter fastened around the waist of the subject. The transmitter contains a receiver that converts the signal from analog to digital data with an analog-digital card. From the transmitter, the signal was passed to the computer and data were analyzed with MyoResearch software (Noraxon USA, Inc., Scottsdale, Arizona).

The NorSwitch footswitch provided real time foot strike data and was comprised of a belt worn amplifier and cables with pluggable sensors. The NorAngle electrogoniometer is a dual biaxial instrument designed for measuring the joint angle during dynamic activity. The manufacturer's error rate is reported to be at ± 2.5°. MyoResearch software allowed for monitoring of surface EMG and signals sent from both the footswitch and electrogoniometer. The EMG, electrogoniometer and footswitch data were collected and sampled at 1000 Hz with a common mode rejection of 130db. The signals were then bandpass filtered (Butterworth) at 10Hz (low) and 500 Hz (high), and amplified (gain 200). The EMG channels were calibrated with the muscles at rest. The electrogoniometer was referenced to zero when the subject was in a weight-bearing stance with the knee fully extended. However, the footswitch was set to zero when the skilled leg was non-weightbearing.

Procedures

After reading the assent script to the child, their age, height and weight were recorded (Appendix C). A motor proficiency test was conducted to ensure that all subjects within the age group were able perform the landing tasks. A modified Berg Balance Scale was used as an assessment tool for static and dynamic balance abilities.[95] This scale was reported to have good test-retest and interrater reliability (ICC, .98),[95] and was originally developed for use with elderly stroke patients. The complete test consists of 14 items but we incorporated the three most advanced tasks into our screening assessment for balance. Scoring consists of a 5-point ordinal scale, with scores ranging from 0-4. Descriptive criteria are provided for scoring each level: a score of 4 indicates that the subject performs independently and meets time and distance criteria, and a score of 0 is used for unable to perform. Subjects were asked to 1) place their alternate foot on step or stool while standing unsupported (Figure 3-1), 2) stand unsupported with one foot in front of the other (Figure 3-2), and 3) balance on the skilled leg for at least 10 seconds (Figure 3-3). In addition, subjects were required to hop on one foot for 5 seconds. These measures were used only for those subjects in Group 1 who were challenged by this simple landing task. Subjects were required to meet the time and distance criteria indicated by a score of 4 for each task.

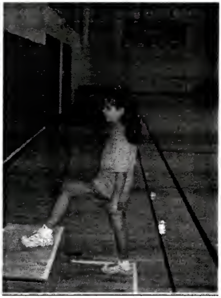


Figure 3-1. Subject placing alternate foot on box.

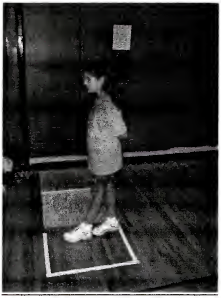


Figure 3-2. Subject standing unsupported with one foot in front of the other.

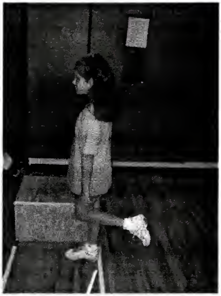


Figure 3-3. Subject maintaining balance on skilled leg.

EMG Preparation

Skin preparation included shaving, abrading, and cleaning with alcohol the area to be monitored prior to electrode application. Disposable, self adhesive dual Ag/AgCl snap electrodes (Noraxon USA, Inc., Scottsdale, AZ) with an inter-electrode distance of 2 cm were placed on the skilled leg over the muscle bellies of the following muscles: vastus medialis, vastus lateralis, medial hamstring and lateral hamstring muscles.[24,96] Specifically, electrodes for the lateral hamstring were positioned halfway on an imaginary line formed between the ischial tuberosity and fibular head. The vastus medialis electrodes were placed on the distal portion of muscle, above and medially from the superior border of patella, while the vastus lateralis electrodes were placed on the bulk of the muscle halfway between the lateral femoral epicondyle and greater trochanter. A reference electrode was placed on the lateral malleolus.

The NorSwitch footswitch was attached to the great toe and the ball of the foot to identify initial ground contact. Subsequently, the NorAngle electrogoniometer was attached to the lateral aspect of the knee joint in line with the greater trochanter, lateral femoral condyle and lateral malleolus to record knee flexion angle at landing.

Landing Task

The landing task required the subjects to stand on one leg atop a 25.4 cm box and jump to the floor, landing on the test (skilled) limb. This box height was reported in a previous study by Rozzi et al.,[24,97] although their subjects were college aged. A study examining plantar-pressure distribution during landing in children with a mean age of 3.2 years used a box height of 20 cm. Therefore, with older subjects being tested in our study, the box height of 25.4 cm seemed appropriate.

Testing took place in a gymnasium for all but two subjects. The subjects who were not tested in the gymnasium were tested outdoors, landing on a concrete playing surface. Children reported to the test session in a t-shirt, shorts, and sneakers. All subjects were given a practice session to familiarize themselves with the task. Subjects were asked to begin the landing task single-leg standing (on the skilled leg) and motionless with their hands on their hips. They were instructed to jump off the box into the marked area and maintain balance for one second after landing on the skilled leg. The marked area was used as a guide for the children in Group 1. They were instructed to land within the taped box. This was necessary because the children in Group 1 would try and jump out and off the box and therefore were not performing the appropriate task. This session took place no longer than 30 minutes before the test session. After subjects were able to meet the criteria for performing the task, equipment was applied and they were given 2-3 additional practice trials (Figures 3-4, 3-5). EMG channels were calibrated with the subject standing motionless in the starting position. Testing followed and data were collected for three trials. A trial was discarded if the subject landed on the contralateral limb or was unable to maintain balance on the skilled leg for one second upon landing.

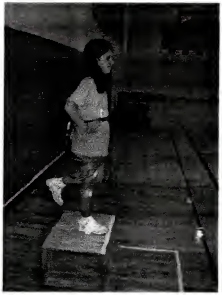


Figure 3-4. Starting position for landing task.

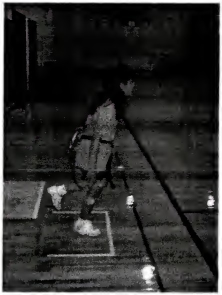


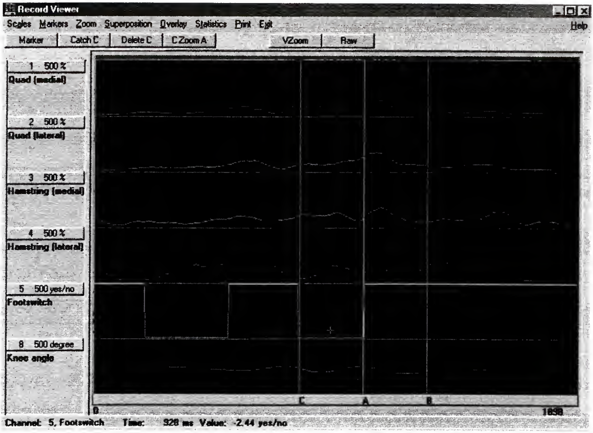
Figure 3-5. Landing position for task.

EMG Analysis

The raw signal of the EMG data was full-wave rectified and processed using the Root Mean Square (RMS) averaged over a 20-millisecond window. The signal was normalized and expressed as a percentage of the mean EMG 250 milliseconds after initial contact.[28 98] Figure 3-6 shows the markers critical for data analysis. Initial contact is represented by marker A, and 250 milliseconds after contact is represented by marker B. Marker C represents the muscle preactivity, occurring 250 milliseconds before contact.

The mean value, defined as a simple average calculation of all the data values within the defined or marked area, was recorded for each muscle. The area value was defined as the area under the curve as calculated by multiplying each data value on the channel by the sampling interval and adding all the resulting values together. This, too, was recorded for each muscle. The mean and area values were obtained for EMG activity that occurred 250 milliseconds prior to ground contact and defined muscle preactivity. These EMG values were averaged across the 3 trials for each muscle.

In addition, the medial and lateral quadriceps values and medial and lateral hamstring values were averaged to obtain a single value for the quadriceps and a single value for the hamstrings activity. This method of combining the EMG data of the medial and lateral quadriceps and medial and lateral hamstrings was described by Colby[21]and Malinzak.[22] The EMG values for each muscle (medial and lateral quadriceps and medial and lateral hamstrings) are expressed as a percentage of mean EMG activity recorded 250 milliseconds after ground contact for each respective muscle. This normalization method was described by Swanik et al.[28] and considered a preferred method over normalizing to a maximal voluntary contraction, as traditionally reported in the literature.



Channel: 5, Footswitch Time: 928 ms Value: -2.44 yes/no

Figure 3-6. An EMG screen showing vertical markers that identify A) Initial contact. B) 250 milliseconds after contact. C)250 milliseconds before contact.

Statistical Analysis

The independent variable in this study was gender (male and female) while the dependent variables were knee flexion angle, muscle preactivity (mean and area), and initial muscle activity at ground contact. Muscle preactivity, defined as 250 milliseconds before ground contact, and muscle activity at contact for the specified muscle were compared between boys and girls in each age group. Knee flexion angles at ground contact were also compared between boys and girls in each group. Independent t-tests were conducted for each dependent variable to determine if gender differences exist.[24] Also, descriptive statistics of the ratio of hamstring and quadriceps activity (EMG H:Q) at initial contact were reported. We examined this ratio because it provides information about the relationship between the hamstrings and the quadriceps at initial contact. The hamstrings are necessary to prevent the anterior tibial translation that can result from a forceful quadriceps muscle contraction and therefore provide additional stability to the knee joint. It is during the initial contact phase that the knee is in a vulnerable position for injury to the ACL and is sustaining a forceful quadriceps muscle action. An *a priori* level of significance was set at $P<.05$ for all comparisons.

CHAPTER 4
RESULTS

The purpose of this investigation was two-fold: 1) to identify differences in knee flexion angle at landing between boys and girls in two different age groups and 2) to determine if there were any differences in muscle activity (preactivity and at initial contact) in response to landing between the boys and girls in each age group.

Subject Participation

A total of 40 children (20 boys and 20 girls) participated in this study. Demographic information is presented in Table 4-1. The right leg was the skilled leg for all subjects.

Table 4-1. Group demographics (mean ± SD)

Group 1	Age (years)	Height (cm)	Weight (kg)
Boys	5.7 ± 0.5	117.9 ± 5.6	22.5 ± 3.1
Girls	5.3 ± 0.5	116.3 ± 9.7	21.9 ± 3.9
Group 2			
Boys	10.8 ± 0.5	159.5 ± 9.7	48.6 ± 15.9
Girls	10.7 ± 0.5	151.4 ± 12.7	42.7 ± 16.3

Knee Flexion Angles

Independent t-tests showed no significant difference (t_{18}=2.09, P=.06) in knee flexion angle at initial ground contact between boys and girls in Group 1 (Figure 4-1) The mean knee flexion angles for the boys and girls were 12°(2.5) and 18°(7.4), respectively. There was a significant difference (t_{18}=2.77, P=.016) in knee flexion angle between boys and girls in Group 2 (Figure 4-2). Mean knee flexion angles for boys and girls in Group 2 were 31°(9.4) and 18°(11.0), respectively.

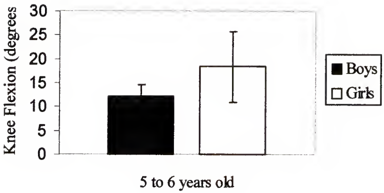


Figure 4-1. Knee flexion angles at contact between boys and girls in Group 1.

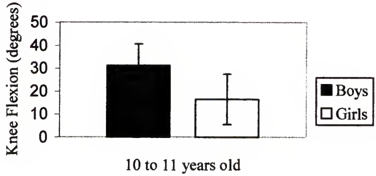


Figure 4-2. Knee flexion angles at contact between boys and girls in Group 2.

Muscle Preactivity

Differences between boys and girls were determined by performing independent t-tests on the mean and area values of the EMG signal for each muscle's activity. These values were normalized to the mean EMG activity that occurred 250 milliseconds after initial ground contact and expressed as percentage·millisecond (%·ms). There were no significant differences in mean values and area values for boys and girls in each group.

A summary table of Group 1 means is presented in Table 4-2 and Group 2 means in Table 4-3.

Table 4-2. Summary table of Group 1 means for EMG preactivity mean values and area values for quadriceps and hamstrings (mean ± SD)

Group 1	EMG mean value (%)		EMG area value (% · ms)	
	Quadriceps	Hamstrings	Quadriceps	Hamstrings
Boys	65.4 ± 31.4	74.9 ± 49.6	16.4 ± 7.8	18.8 ± 12.4
Girls	71.1 ± 26.9	85.3 ± 46.3	17.1 ± 6.3	20.7 ± 9.8
T-test results	t_{18}=.52, P=.61	t_{18}=.58, P=.57	t_{18}=.24, P=.81	t_{18}=.44, P=.66

Table 4-3. Summary table of Group 2 means for EMG preactivity mean values and area values for quadriceps and hamstrings (mean ± SD)

Group 2	EMG mean value (%)		EMG area value (% · ms)	
	Quadriceps	Hamstrings	Quadriceps	Hamstrings
Boys	47.8 ± 20.2	65.6 ± 34.3	12.8 ± 6.8	17.5 ± 10.2
Girls	44.0 ± 32.2	72.1 ± 39.4	11.4 ± 7.8	16.9 ± 9.9
T-test results	t_{18}=.42, P=.68	t_{18}=.09, P=.92	t_{18}=.59, P=.56	t_{18}=.21, P=.83

Muscle Activity at Initial Ground Contact

Independent t-tests revealed no significant differences in quadriceps and hamstring activity at initial contact between boys and girls in each group (Table 4-4). The EMG H:Q ratio was calculated and reported in Table 4-5 to represent the relationship between the quadriceps and hamstrings during initial contact.

Table 4-4. EMG (%) at Contact for Groups 1 & 2 (mean ± SD)

Group 1	Hamstrings	Quadriceps
Boys	105.4 ± 22.2	130.9 ± 32.7
Girls	128.4 ± 41.0	139.6 ± 35.3
	t_{18}=1.29, P=.23	t_{18}=.46, P=.65
Group 2		
Boys	93.1 ± 26.4	99.2 ± 32.8
Girls	90.9 ± 36.2	87.4 ± 37.2
	t_{18}=.14, P=.89	t_{18}=.50, P=.62

Table 4-5. Mean EMG H:Q Ratios at Contact for Groups 1 & 2

Group 1	EMG H:Q Ratio
Boys	0.80
Girls	0.92
Group 2	
Boys	0.94
Girls	1.04

CHAPTER 5
DISCUSSION

The purpose of this investigation was to compare quadriceps and hamstring muscle activity during landing between boys and girls in two age groups. In addition to examining muscle activity, we were interested in comparing the knee flexion angles at initial contact between the boys and girls in each group. Researchers have examined these differences in college-aged athletes, but have not investigated the differences in a younger population. A discussion with regards to the hypotheses set forth in Chapter 1 follows.

As we hypothesized, there was no difference in muscle activity and knee flexion angles between the boys and girls in Group 1 (ages 5-6). Knee flexion angles were similar between boys and girls and it appears as if the girls in this age group have not developed any strategies that may put them at a greater risk for knee injury. The muscle activity that was calculated for the boys and girls was also not significantly different. Children in this age group have traditionally not been involved in extensive training programs that may result in muscle activity differences. Children may participate in youth sport programs that meet 1-2 days per week and are exposed to exercise in physical education class during the school year, although they may formally meet once a week and not follow a set curriculum. Therefore, the amount of physical activity in children this young may not be adequate to alter or display differences in muscle activity patterns between the boys and girls.

Variability in the practice and test trials was seen with further examination of data. The preactivity and initial contact EMG values for each subject were very different from trial to trial and suggest that these children are not proficient at this task.

We hypothesized that there would be differences in muscle activity between the boys and girls in Group 2. In this study, there were no differences in muscle preactivity or muscle activity at initial contact. Although some researchers[24] have detected a difference in muscle activation patterns during cutting or landing maneuvers[21,22], the subjects were collegiate and recreational athletes who had participated in training programs for many years. In this study, it appears as if the children in Group 2 have not participated in a training program rigorous enough to display muscle activity differences between the boys and girls. On the other hand, it may be possible that similar training programs for boys and girls up to the age of eleven may not display the expected differences with regard to muscle activity. The anatomical and physiological changes that females experience during the onset of puberty may offer an explanation for the differences detected in studies with college-aged subjects.

Colby et al.[21] reported an increase in quadriceps activation beginning just before foot-strike during cutting maneuvers with hamstring activation being submaximal at and after foot-strike. Malinzak et al.[22] compared muscle activation during selected athletic tasks between males and females and also found an increase in quadriceps activity and lower hamstring activation for women. Rozzi et al.[24] reported that female athletes demonstrated greater EMG peak amplitude and area of the lateral hamstring when landing from a jump. They suggest that this greater quantity of muscle activity may lend support to the theory that female athletes, who tend to inherently display greater laxity values, achieve joint stabilization through increases in muscle activity. This may be a compensatory mechanism that offers protection to the knee and specifically the ACL. Cowling and Steele[99] studied lower limb muscle synchrony during landing in males and females. In addition to collecting electromyographic data, they examined the tibiofemoral shear forces during a single-limb stance after receiving a straight chest level netball pass. They reported that females had a trend for earlier biceps femoris onset relative to initial contact. Males exhibited a delay in semimembranosus onset relative to initial contact and to peak tibiofemoral shear force, suggesting that this pattern may be more protective of the ACL because it allowed peak hamstring muscle activity to better coincide with the high anterior shear force generated during the initial ground contact.[99]

It is important to understand that an increase in quadriceps activation does not necessarily mean an increase in quadriceps force and thus an increase in anterior shear force on the tibia. Contraction force is determined by activation levels, maximum isometric contraction force, length and shortening velocity.[21,22] The maximum isometric contraction force, muscle length, and muscle shortening velocity were unknown in this study and therefore muscle activation levels cannot be directly correlated with the muscle forces in this study. Also, an eccentric muscle action generates more force than a concentric contraction with less integrated EMG activity and this should be kept in mind when examining the results of this study, especially the muscle activity values reported at initial contact, which is occurring during the eccentric phase of landing.

We supported our hypothesis that females in Group 2 would land with less knee flexion compared to the boys in the same age group. Many studies have reported that females tend to land from a jump or perform "at risk" maneuvers in a more upright position.[22,100-102] Again, most of these studies were performed on college-aged athletes. Our results showed that the average knee flexion angle for the girls in Group 2 was 18° and for boys the average knee flexion angle at contact was 31°. The demographic information for the boys and girls regarding age and height were similar. The mean weight of the boys was 48.6 kg while the girls was 42.7 kg. The influence of body weight on knee flexion angle may offer a suggestion for these differences. Studies have not previously addressed the concern of body weight when discussing the gender differences in knee flexion angle.

Malinzak and colleagues[22] also reported that females had lower knee flexion values compared to males (difference of 8°) throughout the entire cycle of a cross-cutting maneuver. It is important to point out that the angle of the knee for females in this study during initial contact is close to the 21° of knee flexion that has been reported to be position of the knee at the time of injury.[10,19] This is a vulnerable position because with a contraction of the quadriceps, there is an increased strain on the ACL, with the greatest amount of anterior tibial displacement occurring within 10°-30° of full extension.[80,103] Also, smaller knee flexion angles may be associated with increased peak or vertical ground reaction forces.[104]

Lephart et al.[100] reported maximum angular displacement for knee flexion during a single-leg landing to be 17.4° for females and 31.1° for males. Maximum angular displacement represents the difference between ground contact angle and the peak angle attained after ground contact. They also examined the time to maximum angular displacement in males and females. This provides important information about the effectiveness of the lower extremity to dissipate forces generated during landing.

Theoretically, if the amount of time to maximum angular displacement was long and the maximum angular displacement is large, forces will be attenuated and should allow optimal conditions to prevent injury. In this study, we did not examine these measures but they do provide results about the differences in force dissipation for males and females.

The relationship between the hamstrings and quadriceps activity at initial contact is explained by the EMG H:Q ratio. As the data suggest, females in Group 2 are landing with similar muscle activity in the quadriceps and hamstrings. Although this activity does not represent the muscle force being generated, it may further support the theory proposed by Rozzi and colleagues[24] that females demonstrate an increase in hamstring activity as a method of achieving joint stabilization. Huston and Wojtys[23]reported that females relied more on their quadriceps to resist anterior tibial translation and often are considered quadriceps dominant. We did not find this dominant muscle pattern in our EMG H:Q ratio, although we examined this value at initial contact only. Further examination of the EMG H:Q ratio after initial contact is necessary to determine how active the quadriceps and hamstrings are in relation to each other.

A variety of conditioning programs have been designed to alter the landing strategies and muscle activation patterns while performing "at risk" maneuvers such as landing from a jump and cutting. Hewett et al.[25,59] investigated the effects of a 6-week plyometric training program on lower extremity strength, landing mechanics, and incidence of knee injury. They reported that the training program decreased the peak landing force in females while concurrently increasing hamstring muscle strength. Injury incidence, calculated as the knee injury incidence per 1000 athlete-exposures, was significantly decreased in females as a result of the training. Wojtys et al.[105] examined the effect of a 6-week plyometric training program on sagittal-plane ankle, knee, and hip flexion angles. Initial flexion angles at contact of the ankle, knee and hip did not change significantly but the maximum joint angles of the ankle, knee, and hip after landing did significantly increase after training which ultimately would aid in the impact absorption. According to our findings, some aspects of the training programs should be implemented in young children. The difference in knee flexion angle at initial contact between the boys and girls could be diminished if girls between the ages of 6 and 10 were instructed on proper landing strategies that increase the amount of knee flexion and subsequently decrease the stress on the knee joint. Many intervention programs target the high school or collegiate athlete. Altering the landing patterns of these athletes who have performed and practiced the skill for many years is challenging. They have already established the way their body will respond to a cutting, stopping or landing maneuver. As researchers focus on and develop programs to teach proper landing mechanics and also an emphasis on hamstring strengthening, these should be incorporated into the physical education classes in elementary schools. As a result, children would receive proper training in landing strategy early on and potentially decrease the likelihood of sustaining a knee injury in the future.

There is difficulty comparing our EMG values to other studies because of the variety of methods used for normalization. The most common approach for normalizing EMG is that it be expressed as a percentage of a maximal voluntary contraction. The approach we took to normalizing our values was to express the EMG as a percentage of the mean of the muscle activity occurring 250 milliseconds after contact. Swanik and colleagues[28] state that if an average pattern of EMG was constructed for a specific functional activity and the mean or peak amplitude occurring during this pattern is used for the normalization process, then sensitivity of EMG testing increases. When compared to normalization procedures using a maximal voluntary contraction, the mean provides the least intersubject variability. It can be argued that the intrasubject variability increases because in our study muscle preactivity values were normalized to the average muscle activity after contact. With three test trials, each subject had preactivity and initial contact EMG values normalized to three separate values. This is a concern because of the variability seen within the subjects in Group 1. The muscle preactivity and muscle activity at contact varied from trial to trial, yet we do not know if the differences are attributed to actual changes in preactivity/activity at contact or whether it is a change in the activity 250 milliseconds after contact. This may be considered a limitation of the normalization process that is necessary for interpretation of surface EMG.

Conclusion

The difference in landing strategies employed by boys and girls in two different age groups was examined. Muscle activity was not significantly different between the boys and girls in each group. There was a difference in knee flexion angle between the boys and girls in Group 2. The girls landed with a more extended knee (18°) and a more vulnerable position for the ACL. Researchers have reported that the knee is flexed to approximately 21° at the time of injury to the ACL. The fact that the knee is positioned so close to the vulnerable position of the ACL is of concern. Emphasis should be placed on proper landing techniques with more of a flexed knee before the age of 10-11 years old. The muscle activity of the quadriceps and hamstring muscles was not significantly different between the boys and girls in this age group and the differences that are reported in the literature in collegiate athletes may be due to many years of training in which they participate. Future emphasis should be placed on incorporating training programs as part of in-season and off-season conditioning to decrease the likelihood of ACL injury in the female athlete. Specifically, these programs should involve exercises that increase the amount of knee and hip flexion during landing, as well as increase hamstring strength. Age-appropriate programs should be developed for children as young as 5 years old to establish the correct landing techniques from the start.

Future Research

Understanding the ACL injury rate discrepancy between males and females is perplexing. It appears as if researchers are developing intervention and training programs that may reduce the incidence of injury among female athletes. Additional research is needed to evaluate the effectiveness of such programs and determine if these programs are altering the lower extremity joint kinematics enough to see a decrease in injury rate. Also, it appears as if the differences in muscle activity reported in the literature between males and females are apparent in a population older than was tested in this study. Therefore, subjects between the ages of 11-18 years old should be tested to determine when these changes in muscle activity take place between males and females. Future studies should evaluate the landing patterns of boys and girls prepubescent and test them yearly to obtain a clearer understanding of when the different patterns emerge and whether they are a result of the anatomical changes that females experience during the onset of puberty. Further testing of children between the ages of 6 and 10 is necessary to determine at what age the amount of knee flexion at contact differs between boys and girls. Additional variables to analyze would be time to maximum knee flexion, ground reaction forces, and EMG peak amplitude of the quadriceps and hamstrings.

APPENDIX A
PARENTAL CONSENT FORM

Department of Exercise and Sport Sciences
PO Box 118205
University of Florida
Gainesville, FL 32611-8205

Parental Consent Agreement

Dear Parent/Guardian,

I am a graduate student in the Department of Exercise and Sport Sciences, Athletic Training Program at the University of Florida, conducting research on factors that contribute to knee injuries in female athletes. The purpose of this study is to examine the knee muscle activity patterns during landing activities in male and female athletes. The results of this study may help those involved in the prevention and treatment of athletic injuries (ie. physicians, athletic trainers and physical therapists) as well as those who physically train and condition athletes (coaches and strength and conditioning specialists). These findings may also help in developing prevention programs that could decrease the likelihood of knee injuries, especially in the female athlete. The results may not directly help your child today, but may benefit other athletes in the future. With your permission, I would like to ask your child to volunteer for this research.

Testing will take 30 minutes. You and your child will be asked a few questions regarding the child's level of participation in athletics. Height, weight and age will be recorded for each child. Your child will be asked to wear shorts, a t-shirt and sneakers. Your child will have 5 practice trials of hopping down on one leg off a box height of 10 inches. After the practice trials, the skin on the child's landing leg will be cleaned with rubbing alcohol and 4 adhesive electrodes will be applied to the thigh muscles. A sensor will be attached to the knee and the bottom of the foot to signal contact with the ground. After the electrodes and sensors are in place, your child will be asked to hop down from the box on one leg and hold the landing position for 1 second. Muscle activity from 5 test trials will be recorded. Your child's identity will be kept confidential to the extent provided by law. Your child's name will be replaced with a code number and results will only be reported in the form of group data.

You and your child have the right to withdraw consent from your child's participation at any time without consequences. There are no known risks or immediate benefits to the participants. No compensation is offered for participation. Results of the study will be available following completion of data and statistical analysis upon request. If you have any questions about this research protocol, please contact me at (904) 737-5564 or my faculty supervisor, Dr. Mark Tillman, at (352) 392-0584. Questions or concerns about your child's rights as a research participant may be directed to UFIRB office, University of Florida, Box 112250, Gainesville, FL 32611, (352) 392-0433

Bernadette Buckley, MEd, ATC

I have read the procedure described above. I voluntarily give my consent for my child, ____, to participate in Bernadette Buckley's study of muscle activity patterns during landing. I have received a copy of this description.

Parent/Guardian:____ Date:____________

2nd Parent/Witness:______________________________________ Date:____________

APPENDIX B
CHILD ASSENT SCRIPT

Department of Exercise and Sport Sciences
PO Box 118205
University of Florida
Gainesville, FL 32611-8205

Child Assent Form

Dear Child,

I am a student interested in learning about how your muscles work when you land from jumping. I will first measure how tall you are and see how much you weigh. Also, I will ask how old you are.

You will be asked to practice hopping down off a box and landing on one leg. You will get to practice 5 times. We will clean the skin of your leg and apply stickers to your thigh. These stickers will tell me how much your muscles are working. Two more stickers will be placed on your foot and knee. They tell me when you land on the ground. You will then hop down from the box and land on one leg and stay there for a second. You will do this 5 times.

If at any time you don't want to do the jumping, tell me and you can stop.

Would you like to participate?

APPENDIX C
DATA COLLECTION FORM

Data Collection Sheet

Subject Code:________ Date____________

Age_____ Height_____ Weight_____ Skilled Leg R or L

Gender M or F
Initial Contact
Knee Flexion:
Trial 1 _____
Trial 2 _____
Trial 3 _____
Average Knee Flexion _____

Quadriceps Activity:
Lateral:
Trial 1 ________
Trial 2 ________
Trial 3 ________

Medial:
Trial 1 ________
Trial 2 ________
Trial 3 ________
Average Quadriceps Activity

____

Hamstring Activity:
Lateral:
Trial 1 ________
Trial 2 ________
Trial 3 ________

Medial:
Trial 1 ________
Trial 2 ________
Trial 3 ________
Average Hamstring Activity

____
Quadriceps Activity:
Lateral: Mean (Area)
Trial 1 ________
Trial 2 ________
Trial 3 ________

Preactivity

Medial: Mean (Area)
Trial 1 ________
Trial 2 ________
Trial 3 ________
Average Quadriceps Activity
Mean (Area)________

Hamstring Activity:
Lateral: Mean (Area)
Trial 1 ________
Trial 2 ________
Trial 3 ________

Medial: Mean (Area)
Trial 1 ________
Trial 2 ________
Trial 3 ________
Average Hamstring Activity
Mean (Area)________

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BIOGRAPHICAL SKETCH

Bernadette Drew Buckley was born in Southampton, New York in 1970 and is the fourth oldest of thirteen children. She attended Mercy High School and continued her education at Canisius College in Buffalo, NY where she received a BS degree in Athletic Training/Physical Education in 1993. Upon graduation from Canisius, Bernadette entered a 13-month graduate program at the University of Virginia in Athletic Training. She worked as a graduate assistant athletic trainer for women's soccer and men's lacrosse. In December of 1993 she passed the National Athletic Trainers' Association Board of Certification Examination and became a certified athletic trainer.

After completing her graduate work at Virginia, Bernadette worked as an assistant athletic trainer at Catholic University of America in Washington, DC. The next year she worked in a clinic/high school in Rockville, MD as an athletic trainer and remained there for 3 years. In 1998, she moved to Gainesville, Florida to pursue a PhD in Athletic Training/Sports Medicine under the guidance of Dr. Thomas Kaminski. While at UF she worked as a research assistant for Dr. Keith Meister and also spent 2 years as a teaching assistant. After completing her PhD, she will teach in the Department of Athletic Training and Physical Therapy at the University of North Florida. Bernadette is married to Jerry Buckley. They have a 21-month old son, Patrick, and a 1-month old son, Daniel.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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This dissertation was submitted to the Graduate Faculty of the College of Health and Human Performance and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

May 2003

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